Overview of EMP Research at LLNL

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Activity on EMP is growing at LLNL: the people

- Familiar to many here:
  - Paul Miller (WCI / AX Div.) – overall leadership
  - Dave Larson (WCI / AX Div.)
  - Hans Kruger (WCI / AX Div., ret.)
- Newly participating, from LLNL's Fusion Energy program
  - Bruce Cohen (Physics Div., Fusion Theory group)
  - Alex Friedman (Physics Div., Heavy Ion Fusion group)
  - Dave Grote (Physics Div., Heavy Ion Fusion group)

We note with sadness the untimely passing of our colleague, mentor, and friend, Dennis Hewett

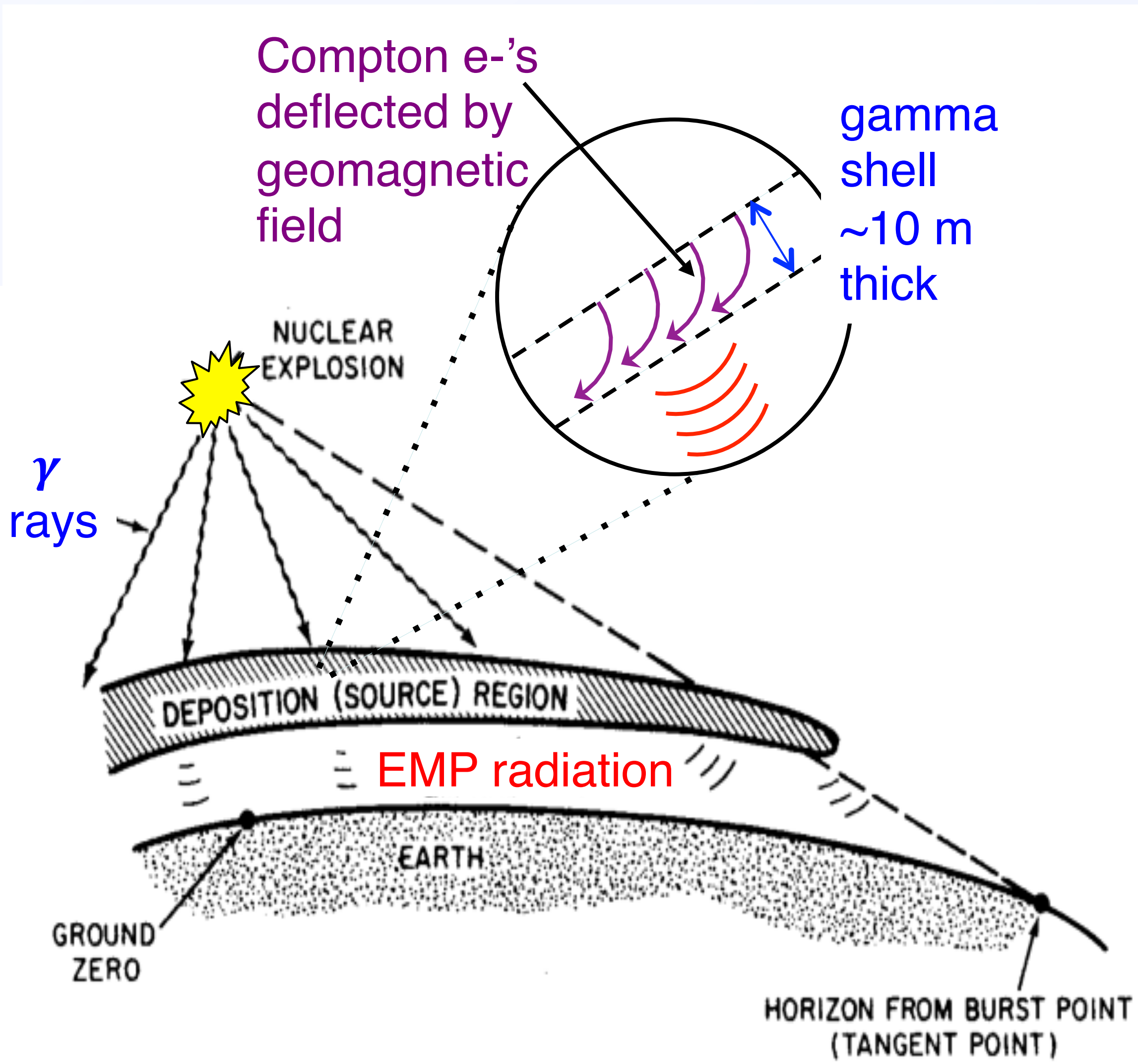
Dennis passed away on April 5, 2012, at the age of 64.

Activity on EMP is growing at LLNL: the research

- Ongoing activities
  - Dave Larson: high-altitude topics, debris dispersal effects, …
  - Hans Kruger: analysis and MACSYNC simulations
- LDRD proposal for FY14 (I will talk about this)
  - "Self-Consistent 3D Calculations of the Electromagnetic Pulse"
  - Dave Larson (PI), Bruce Cohen, Alex Friedman, Dave Grote, Hans Kruger, postdoc TBD
  - Received favorable reviews; funding TBD
- Modest new programmatic effort (Dave Grote will talk about this)
  - First: exploration of newly recognized (by Kruger) effects
  - Using modified 1-D codes to explore, *e.g.*, gamma shadowing
  - Dave Grote, Alex Friedman, Bruce Cohen
  - Hope to expand scope

Proposed LDRD for FY14-16

LDRD Goal: Develop and begin exploiting a new capability for EMP propagation studies



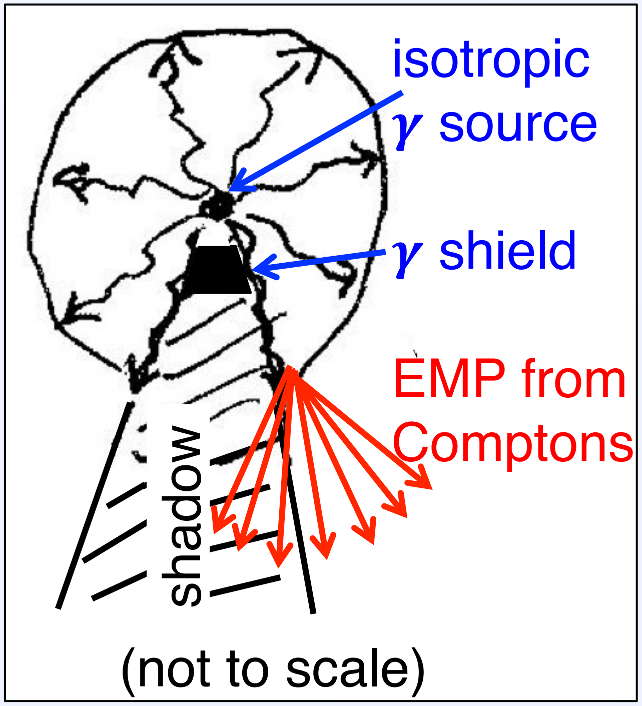
- 3D and self-consistent
- Advanced methods, leveraging LLNL / LBNL's Warp code

Prior art in EMP propagation simulations

- Widespread use of 1-D codes, especially CHAP & HEMP
  - Neglect multi-dimensional effects, *e.g.*, gamma shadow
  - Neglect electron displacement along LOS from multiple scattering
- Hans Kruger is using his MACSYNC code
  - Monte-Carlo approach; uses MCNP at its core
  - Exploring the above effects
- LANL is developing a modern capability
  - 3-D FDTD EM; focus on urban scenarios
  - Suitable for up to a few kilometers
  - Links to MCNP for gamma and electron transport
- L3, Sandia, and AWE maintain independent efforts

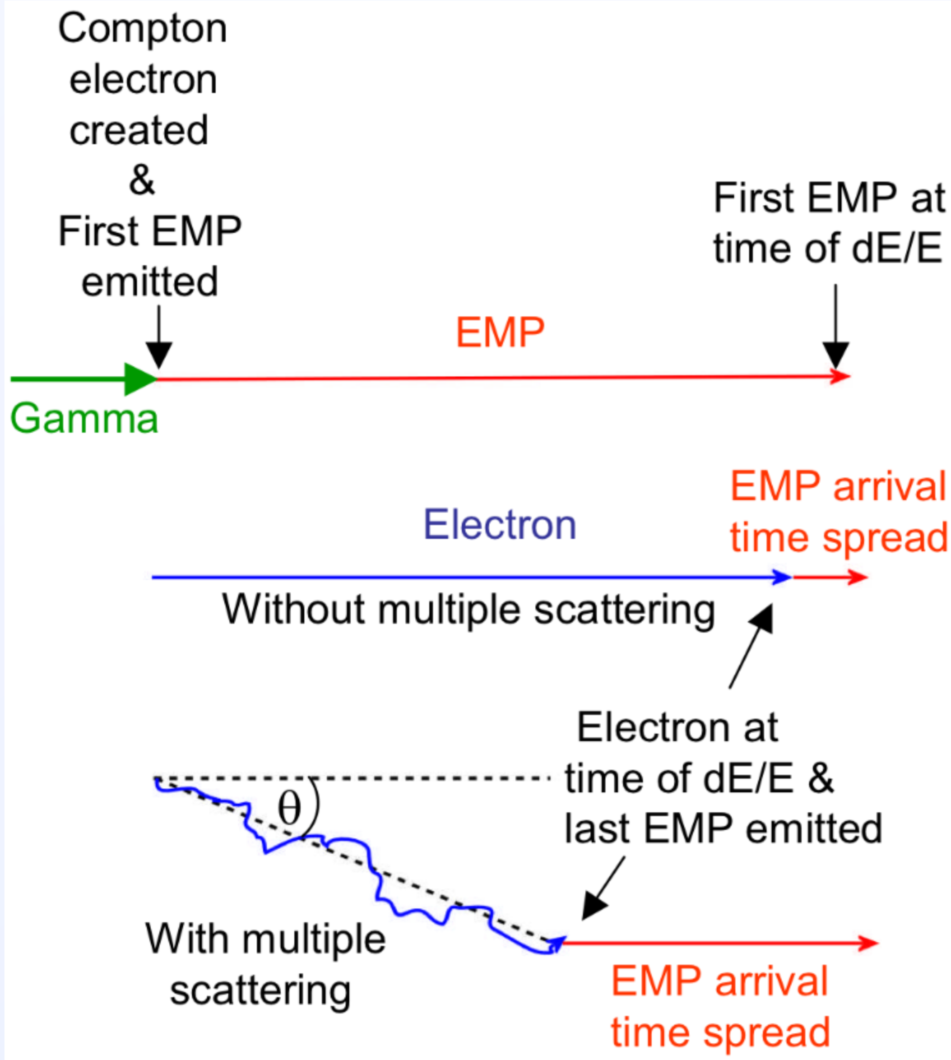
Gamma shadowing and other multidimensional effects require a 3-D description

- In a non-shadowed region:
  - gammas create Compton electrons
  - Comptons create secondaries
  - secondaries create conductivity
  - Conductivity → "saturated" EMP amplitude
- In a shadowed region:
  - conductivity is much lower
  - EMP saturates only via the air avalanche breakdown it creates
  - field amplitude could be 10x higher (H. Kruger)
- Structures & terrain also introduce 3-D physics
  - shield gammas
  - directly block / reflect / channel the EMP



Electron dynamics in, *e.g.*, CHAP is incomplete

- Multiple scattering leads to an angular displacement (this is accounted for).
- The electrons, however, “lag behind” as a result of the scattering.
- The spatial displacement is *not* accounted for.
- H. Kruger has shown that it leads to a smearing of the pulse.
- We may expect a much longer rise time.



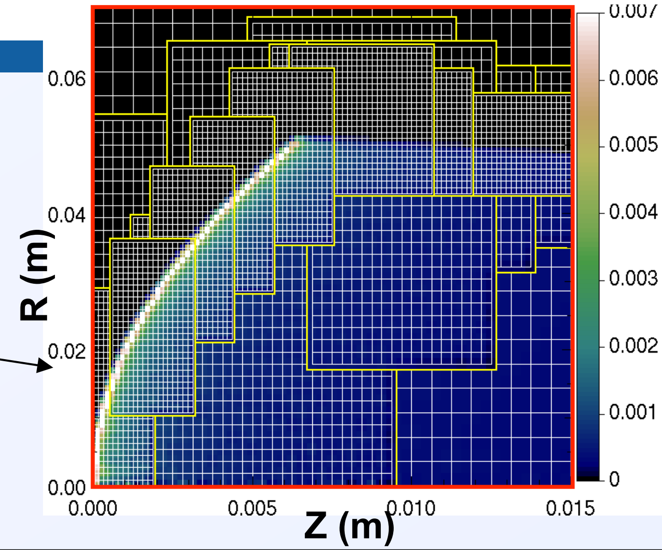
Technical approach for EMP simulation LDRD

- Extensive LLNL and LBNL work on the Warp code will be leveraged.
  - 3D / 2D EM / ES PIC for beam and plasma simulations
  - Benchmarked on ion beam experiments, laser acceleration, anti-hydrogen trap, many other applications
  - Grote, Friedman, and LBNL's Vay are principal developers
- Advanced numerical methods have recently been developed for laser acceleration and other beam physics problems.
  - They are well suited for the (surprisingly similar) EMP problem
  - They are available to the team (already implemented in Warp)

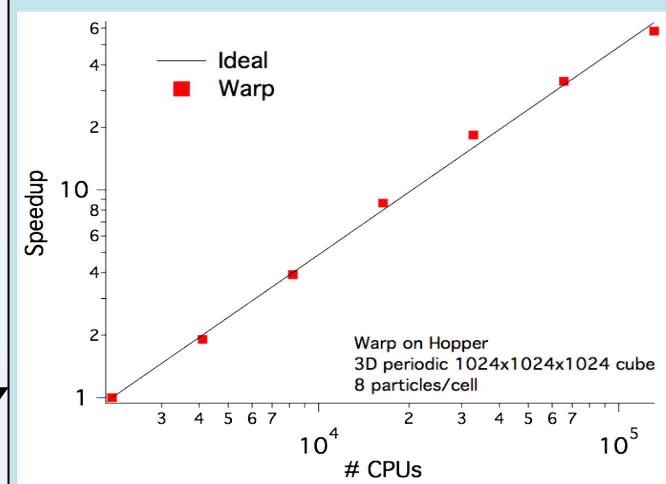
We plan to develop a new EMP code, building on Warp's framework and components, and incorporating the additional physics required for EMP problems.

Warp: a parallel framework combining features of plasma (Particle-In-Cell) and accelerator codes

- **Geometry:** 3D (x,y,z), 2-1/2D (x,y), (x,z) or axisym. (r,z)
- **Python and Fortran:** "steerable," input decks are programs
- **Field solvers:** Electrostatic - FFT, multigrid; implicit; AMR
  Electromagnetic - Yee, Cole-Kark.; PML; AMR
- **Boundaries:** "cut-cell" --- no restriction to "Legos"
- **Applied fields:** magnets, electrodes, acceleration, user-set
- **Bends:** "warped" coordinates; no "reference orbit"
- **Particle movers:** Energy- or momentum-conserving; Boris, large time step "drift-Lorentz", novel relativistic Leapfrog
- **Surface/volume physics:** secondary e^- & photo-e^- emission, gas emission/tracking/ionization, time-dependent space-charge-limited emission
- **Parallel:** MPI (1, 2 and 3D domain decomposition)



Warp 3D EM/PIC on Hopper



Warp has proven useful to multiple applications

- **HIFS-VNL (LBNL,LLNL,PPPL):** ion beams and plasmas
- **VENUS ion source (LBNL):** beam transport
- **LOASIS (LBNL):** LWFA in a boosted frame
- **FEL/CSR (LBNL):** free e^- lasers, coherent synch. radiation
- **Anti H- trap (LBNL/U. Berkeley):** model of anti H^- trap
- **U. Maryland:** UMER sources and beam transport; teaching
- **Ferroelectric plasma source (Technion, U. MD)**: source
- **Fast ignition (LLNL):** physics of filamentation
- **E-cloud for HEP (LHC, SPS, ILC, Cesr-TA, FNAL-MI):** merged code Warp-POSINST
- **Laser Isotope Separation (LLNL):** now defunct
- **PLIA (CU Hong Kong)**: pulsed line ion accelerator
- **Laser driven ion source (TU Darmstadt)**: source
- **Magnetic Fusion (LLNL)**: oblique sheath at tokamak divertor

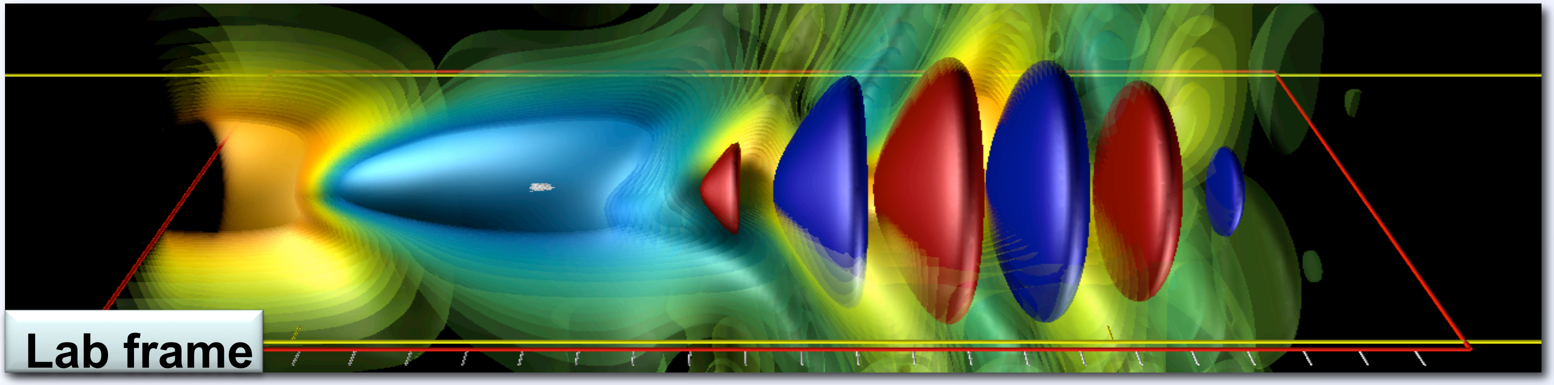
We will build on Warp's framework and models

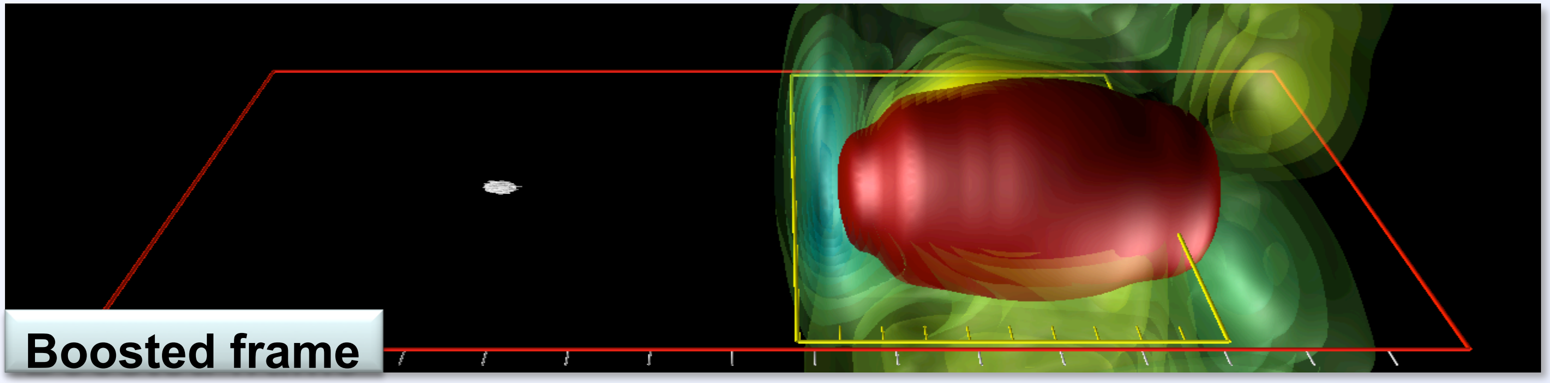
- Compton electrons will be generated in a Monte-Carlo procedure.
- Collision models exist, but will need to be generalized with suitable cross-sections.
- Conductivity model will be based on Hans Kruger's fits to MCNP output.
- Would like to explore with this community options for improved models.

Lorentz-boosted frame (rotation in space-time) brings disparate scales closer together and reduces computational effort

Spatial oscillations are converted to time beating

(scaled BELLA simulation by Jean-Luc Vay, LBNL, using Warp)



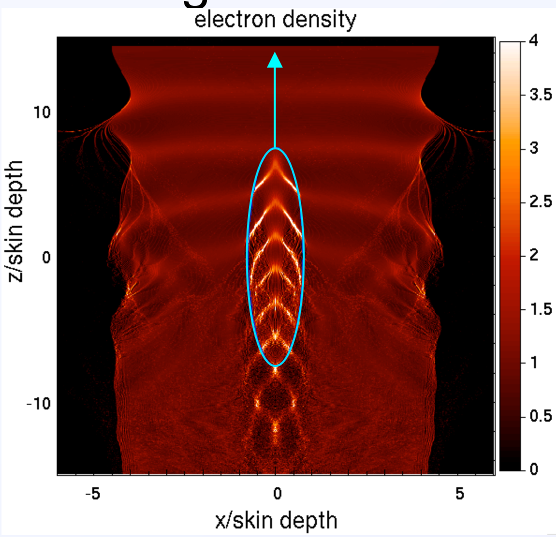


The method has been applied to studies of free-electron lasers, laser-plasma accelerators, and particle beams interacting with electron clouds

Mesh-refined Warp simulation of electromagnetic ion-beam-induced plasma wake illustrates speedup

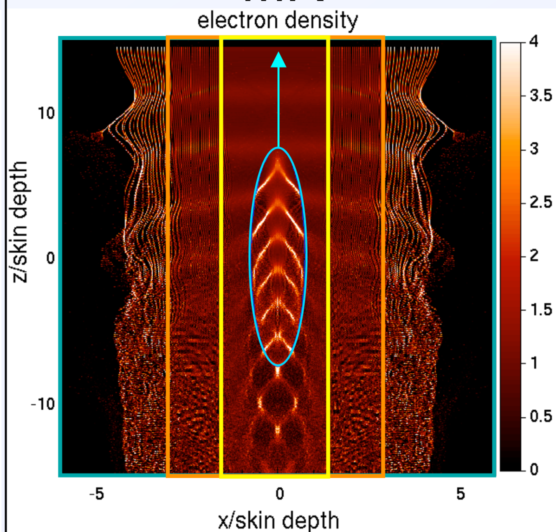
no refinement

2-D high resolution

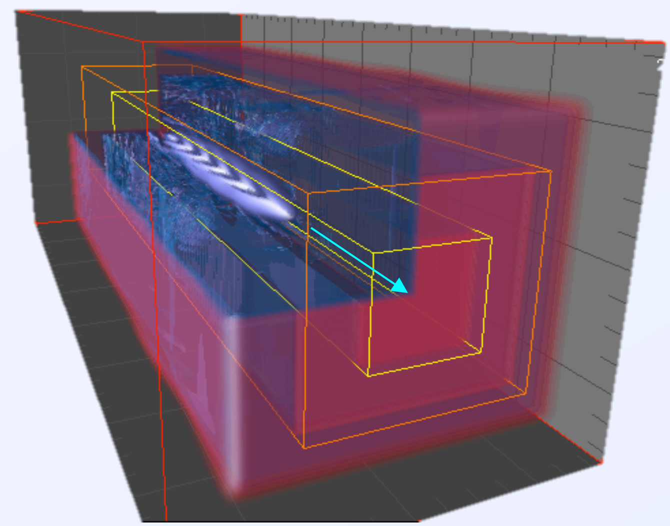


2 levels of mesh refinement (MR)

2-D low resolution + MR

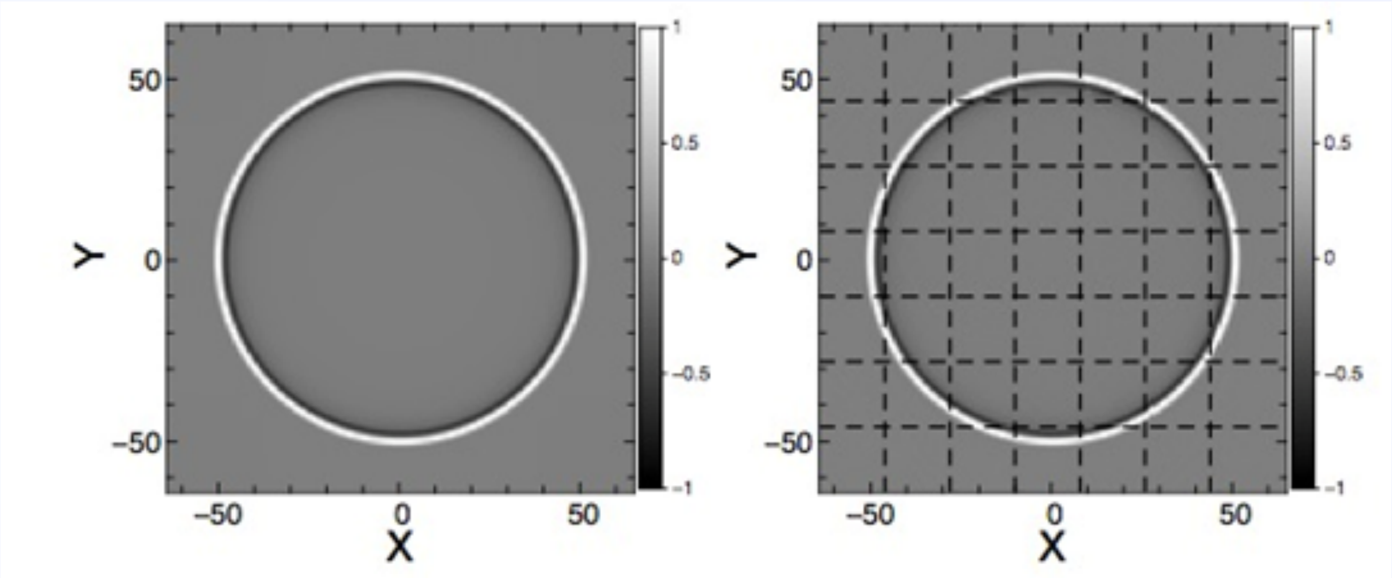


3-D



- Speedup was ten-fold in 3-D (same Δt for all refinement levels)
- MR promises benefits for simulating an EMP pulse in free space impinging on structures
- Work by Jean-Luc Vay and Dave Grote

Dispersion-free pseudo-spectral Maxwell solver



- A classical method (Haber) that only recently has been parallelized (via domain decomposition)
- Clever trick (Vay, Godfrey, Haber) takes advantage of finite speed of light allowing highly scalable parallelization
- Essential for propagating signals over large distances, *e.g.,* from the ground to space

This is a new effort …

- We would very much enjoy collaborating with others in the field
- Can explore:
  - Physics models
  - Numerical approaches
  - Benchmarking opportunities
  - Collaboration on applications
  - … and more

New Programmatic Directions

Initial work is on developing better understanding of the newly recognized effects

- We are exploring whether small modifications to CHAP can be made to approximate the two effects.
  - MACSYNC has limitations – it does not include self-consistency, and air breakdown and avalanche effects.
- We are taking advantage of CHAP's avalanche model to help in understanding how the avalanche effects the increased EMP that arises from gamma shadowing.
- We are examining if there is a meaningful way to patch CHAP to include the effect of multiple scattering on the rise time (for unshadowed geometries).
- This is a qualitative exploration aimed at developing insight.
- Full understanding of the effects require 3-D simulation.

Our work with CHAP is an initial effort.

- Some of us have only recently begun working in this area and are taking small steps to develop experience and background.
- We would be happy to have discussions and collaboration.
- We are currently using an older Fortran version of CHAP that we had readily available, but are interested in learning about new features and capabilities in the LANL version.